Unit (2)

Lesson (1)

Mole and chemical equation

Chemical equation

→ *When oxygen gas reacts with magnesium, magnesium oxide is formed. Such*

*Reactions are described by balanced equations known as "**chemical equations**"*

$$2Mg_{(s)} + O_{2(g)} \xrightarrow{\Delta} 2MgO_{(s)}$$

Chemical equation properties

1- It is composed of the chemical formulas and symbols of the reactants and products

*2- Both sides of the equation (the reactants and products) are separated by an arrow describing the conditions and direction of the reaction **(in the previous equation, the triangle on the arrow describes heat)***

3- It describes the quantity of reactants and products (the no. of molecules)

*4- It describes the state of reactants and products – **solids are denoted by (s), liquids (l), gas (g) and aqueous solutions (aq.)** as shown in the previous equation*

→*Chemical equations should be balanced, which means that the no. of molecules of reactants should equal the no. of molecules of products. This is known as **"law of mass conservation"***

***Chemical equation:** The representation of chemical reaction using chemical symbols, formulas of reactants and products, and the description conditions of reaction.*

Note:

***Molecule:** is the smallest particle in a chemical element or compound that has the chemical properties of that element or compound and exists alone*

***Atom:** The smallest building unit of matter which takes part in chemical reaction*

***How to balance a chemical equation:**-*

→ *to balance a chemical equation, we should make sure that the right side of the equation has the same atoms of the left side of it.*

Example (1)

Balance the following equations:-

1- $Al + O_2 \rightarrow Al_2O_3$

2- $NaNO_3 \ \Delta \rightarrow NaNO_2 + O_2$

Solution:-

*1- we find that there are 3 oxygen atoms on the right side of the equation, while there are only 2 on the left side of it. To balance the no. of oxygen atoms on both sides, we should increase the no. of oxygen atoms on both of them to 6 (**6 is the least common multiple of 2 and 3)***

$Al + 3O_2 \rightarrow 2Al_2O_3$

There are four aluminium atoms on the right side of the equation, while there's a single atom on the left side. To balance the no. of aluminium atoms on both sides, we increase the no. of atoms in left size to 4 aluminium atoms

$4Al + 3\ O_2 \xrightarrow{\Delta} 2\ Al_2O_3$

2- The no. of oxygen atoms on the right side of the equation is 3, while that on the right side of the equation is 4, to balance the no. of oxygen atoms, we increase the no. of oxygen atoms on both sides to 6

$$NaNO_3 \xrightarrow{\Delta} NaNO_2 + O_2$$

Ionic reactions

→ *Some physical processes, as the dissociation of some molecules into ions when they dissolve in water, are described by **"ionic reactions"***

→ ***1-** dissolving sodium chloride in water, we describe it by the following ionic reaction:-*

$$NaCl_{(s)} \xrightarrow{water} Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

2-(Neutralization reaction) (sulphuric acid reacts with sodium hydroxide)forming sodium sulphate and water, we describe the reaction as the following:-

$$2NaOH_{(aq)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)}$$

We can describe the previous neutralization reaction by an ionic equation:-

$$2Na^{+}_{(aq.)} + 2(OH)^{-}_{(aq.)} + 2H^{+}_{(aq.)} + SO_4^{2-}{}_{(aq.)} \longrightarrow 2Na^{+}_{(aq.)} + SO_4^{2-}{}_{(aq)} + 2H_2O_{(l.)}$$

→ *We will notice from the previous ionic equation that the ions of sodium and sulphate didn't take part in chemical reaction, but they form bonds with water molecules forming sodium sulphate.*

→ *Ionic equation the reactions of ions with each other forming new compounds. Therefore, ions of sodium and sulphate were omitted because they didn't react with other ions. The final ionic equation of this neutralization reaction is:-*

$$H^{+} + (OH)^{-} \longrightarrow H_2O$$

3-Precipitation reaction: *when adding potassium chromate ($K_2C_rO_4$) to silver nitrate solution ($AgNO_3$), insoluble silver chromate(Ag_2CrO_4) is formed as a red ppt.*

$$K_2CrO_{4(aq)} + 2AgNO_{3(aq)} \rightarrow 2KNO_{3(aq)} + Ag_2CrO_{4(s)}$$

Find the ionic equation of the previous reaction.

Solution:-

$$2K^{+}_{(aq)} + CrO_4^{2-}{}_{(aq)} + 2Ag^{+}_{(aq)} + 2NO_3^{-}{}_{(aq)} \longrightarrow 2k^{+}_{(aq)} + 2NO_3^{-}{}_{(aq)} + Ag_2CrO_{4(s)}$$

→ *Potassium and nitrate ions are removed because potassium nitrate is an aqueous solution. Therefore, they didn't react with any other ions.*

$CrO_4^{2-}{}_{(aq)} + 2Ag^{+}_{(aq)} \longrightarrow Ag_2CrO_{4(s.)}$ *Red precipitate*

The Mole

The term "Mole" in the international System of Units (S.I) **to express the amounts of substances used and resulted from the chemical reaction.**

Mole and mass of matter

Mole: is the molecular mass of a substance expressed by grams.

-If the mass no. of carbon (C) equals 12 a.m.u then one mole of carbon atoms represents 12 grams of carbon atoms.

Molecular mass: *The sum of the masses of the atoms forming molecules of a compound*

Example:-

The molecular mass of carbon dioxide molecule (CO_2) is the sum of the masses of 2 oxygen atoms and 1 carbon atom.

Therefore, the molecular mass of CO_2 molecule = 12+(2x16) = 44 a.m.u

1 mole of CO_2=44 gm

-In case of ionic compounds as $CaCl_2$ in which the building units can be expressed by ***formula unit***

-The mole of oxygen gas (in the form of molecules) O_2 = 2x16= 32 gm

-The mole of oxygen gas (in the form of atoms) = 16 gm

→ *There are some elements whose molar masses change by the change of their physical state (solid, liquid, gas) for example:-*

Phosphorus molecule*: ⟶ in gaseous state consists of 4 atoms (P_4)*

↘ in solid state consists of only 1 atom

Sulphur: *⟶ in gaseous state is octatomic (consists of 8 atoms),*

in solid state consists of only 1 atom

$$\textbf{The no. of moles in matter} = \frac{\textbf{The mass of matter (in grams)}}{\textbf{molar mass (g/mol)}}$$

Limiting reactant

→ *We said that chemical reactions require certain amounts of reactants to get the required amount of products But if the amount of a certain reactant is smaller than the required amount, it's completely consumed. Such small amounts of reactants are known as* ***"Limiting reactant"***

Limiting reactant: *The substance that is totally consumed when chemical reaction is complete due to its lack*

Example: magnesium reacts with oxygen according to the equation

$$2Mg_{(s)} + O_{2(g)} \xrightarrow{\Delta} 2MgO_{(s)}$$

What is the limiting reactant of the reaction as using 32 g of oxygen with 12 g of magnesium?

(Mg=24, O=16)

Solution

Number of moles of O_2= $\frac{32}{32}$ *=1mol.*

Number of moles of MgO =1 mol O_2x $\frac{2\ mol\ MgO}{1mol\ of\ O2}$ *=2mol MgO*

Number of moles of Mg= $\frac{12}{24}$ *=0.5mol.*

Number of moles of MgO =0.5mol x $\frac{2mol\ MgO}{2mol\ Mgt}$ *=0.5mol*

So magnesium is the limiting reactant of the reaction because the number of moles of magnesium oxide resulted is lesser in number.

Mole and Avogadro's number

Amedeo Avogadro reached the number of atoms or ions or molecules found in one mole of substance is a constant number is approximately $6.02x10^{23}$.

Example:

Calculate the number of carbon atoms found in 50 g of calcium carbonates, knowing that:

[Ca = 40 , C = 12 , O = 16]

Solution:

Mole of calcium carbonates CaCO3 = 16 ✕ 3 + 12 + 40 = 100 g

As one mole of CaCO3 contains 1 mol of carbon atoms (C)

i.e. 100 g contains → 1 mol of carbon atoms (C)

therefore, 50 g contains → X mol

X (Number of carbon atom moles) = $\frac{1 \times 50}{100}$

= 0.5 mol

` Number of carbon atoms = 0.5 ✕ 6.02 ✕ 1023 ✕ 0.5 = 3.01 ✕ 10^{23} atom

Mole and volume of gases

It's known that the volume of gas is the volume of its container, but scientists discovered that moles of all gases occupy certain volume of 22.4 litres if they are put in certain conditions called "Standard temperature and pressure (STP)"

***STP:** The presence of matter in temperature of 0 degree Celsius (273 Kelvin) and pressure of 760 mm. Hg (1 atomic pressure)*

→ This means that a mole of methane gas (CH_4) occupies volume of 22.4 litres (if it's in (STP), and the same to a mole of Hydrogen gas (H_2) and any gas.

***Avogadro's law:** at constant temperature and pressure, the volume of gas is directly proportional to it's number of moles.*

Volume of gas (in liters) at S.T.P = 22.4 x no.of moles

Example:

Calculate the volume of oxygen needed to produce 90 g of water by reacting with an excess
amount of hydrogen at the standard temperature and pressure (STP). [O = 16 , H = 1]

Solution:

$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$

2 mol 1 mol 2 mol

Molar mass of water $H_2O = 16 + 1 \times 2 = 18$ g

From the equation , we find that :

1 mol of O_2 ⟶ 2 mol of H_2O

X mol of O_2 ⟶ 90 g of H_2O

X (Number of oxygen's moles) = $\frac{1 \times 90}{36}$

= 2.5 mol

Volume of oxygen gas = 22.4 ✕ 2.5 = 56 L

Example (1)

Calculate the volume of 64 gm of oxygen gas in STP conditions (O=16)

Solution:-

If one mole of oxygen =16+16= 32 gm (diatomic element)

The no. of moles = 64 /32= 2 moles

The volume of oxygen gas = 22.4 x the no. of moles = 22.4 x2 =44.8L

Avogadros postulate: *equal volumes of different gases contain the same number of molecules under the same standard temperature and pressure.*

Ex:

$H_{2(g)} + Cl_{2(g)}$ ----- → $2HCl_{(g)}$

1mol 1mol 2mol

22.4L 22.4 2x22.4L

$6.02x10^{23}$ $6.02x10^{23}$ $2x6.02x10^{23}$

Molecules molecules molecules

We conclude that

The mole: the quantity of matter that contains $6x10^{23}$ molecules or atoms or ions or formula units of substance.

Questions of lesson one

1- Choose the correct answer

1- When 50 gm of $CaCO_3$ decomposes thermally, ……..gm of CaO is formed (Ca = 40, C=12, O=16)

A- 28 B- 16 C- 76 D- 35

2- The volume of hydrogen required to form 11.2 L of water is…….

A- 22.4 L B- 11.2 L C- 68.2 L D- 44.8 L

3- The unit used in IS for measuring the quantity of matter is…..

A- Mole B- Joule C- Calenda D- Kelvin

4- The mass of 44.8L of ammonia gas (NH_3) in STP conditions is ……gm.

(N=14, H=1)

A- 0.5 B-2 C- 17 D- 34

5- If an amount of sodium has $3.01x10^{23}$ atoms, so its mass is ……..gm

A- 11.5 B- 0.5 C- 23 D-46

6- The chemical equation should be balanced according to .....

A- Avogadro's law B- Gay-Lussac's law C- law of mass conservation

D- Law of energy conservation

7- 0.5 mole of carbon dioxide gas (CO2) weighs….. gm (C=12, O=16)

A- 22 B- 44 C-66 D-88

8- When 64 gm of oxygen reacts with hydrogen, ….. liters of water vapor (H_2O) are formed

A- 11.2 B- 22.4 C- 44.8 D- 89.6

9- The no. of moles in 36g of water equals……. (H=1,O=16)

A- 1 B-2 C- 3 D- 4

2- Solve the following problems

1- Find the no. of sodium ions resulted from the dissolution of 117g of sodium chloride (NaCl) in water (Na=23,Cl=35.5)

2- 26.5g of sodium carbonate (Na_2CO_3) reacted with an abundant amount of hydrochloric acid in STP conditions (Na=23,C=12, O=16) find:-

a- The no. of water molecules

b- The volume of carbon dioxide gas

3- Calculate the no. of moles in 144gm. of carbon (C=12)

4- Calculate the mass of 2.4 moles of calcium carbonate ($CaCO_3$)
(Ca=40, C=12, O=16)

5- Calculate the volume of 56g of nitrogen gas in STP conditions (N=14)

6- 23g of sodium (Na) reacted with water(H_2O) forming sodium hydroxide (NaOH) and hydrogen gas (Na=23, O=16, H=1), Find:-

a- The no. of sodium ions resulted from the reaction

b- The volume of evolving hydrogen gas

3- Balance the following equations

1- $N_{2(g)} + H_{2(g)} \xrightarrow{\Delta} NH_{3(g)}$

2- $Cu(NO_3)_{2(s)} \xrightarrow{\Delta} CuO_{(s)} + NO_{2(g)} + O_{2(g)}$

*3- **3** $Al_{(s)} + O_{2(g)} \xrightarrow{\Delta} Al_2O_{3(s)}$*

4- Represent the following reactions by balanced ionic equations

1- The reaction of sodium chloride with silver nitrates forming a white ppt. of silver chloride and sodium nitrates

2- The reaction of Nitric acid with potassium hydroxide solution forming potassium nitrate solution and water.

Lesson (2)

The calculation of chemical reactions

The mass percent:

$$Element\ mass\ percentage = 100x \frac{\textbf{the element mass in the sample}}{\textbf{total mass of the sample}}$$

Example

Calculate the weight percent of oxygen in carbon dioxide gas (C=12,O=16)

Solution

The mole of carbon dioxide CO_2 = 12+16+16=44 gm

The mass of oxygen atoms forming CO_2 mole = 16 + 16 = 32 gm

The weight percent of oxygen = (32 / 44)x 100 = 72.7%

Example (2) *calculate the percentage of nitrogen in ammonium nitrate NH_4NO_3*

Solution:

$$N\% = \frac{\textbf{mass of nitrogen}}{\textbf{molar mass of ammonium nitrate}} x100 = \frac{(2x14)}{(2x14+4+(3x16))} x100 = 35\%$$

Example (3)

Calculate the weight percent of iron in ferric oxide (Fe_2O_3) (Fe=56, O=16)

Solution:-

Mole of ferric oxide = 56+56+16+16+16 = 160 gm

The mass of iron atoms forming one mole of ferric oxide = 56 + 56 = 112 gm

Weight percent of iron = (112/160) x 100 = 70%

***Calculating the chemical formula**:*

Chemical formulae have two main kinds:-

1- Empirical formula

2- Molecular formula

***Empirical formula:** The formula that describe the simplest ratio between the atoms of the elements forming the compound molecules*

Example:-

*The formula of Propylene is C_3H_6 , if we divided both numbers by 3, the empirical formula will be CH_2 (**empirical formula describes only the ratio between the components of molecules)***

<u>How to calculate chemical formula</u>

We can calculate them using the weight %of the elements forming the compounds

Example:-

Calculate the empirical formula of a compound containing 25.9% nitrogen and 74.1% oxygen (O=16, N=14)

Solution:-

The no. of nitrogen moles = weight percent /molar mass = 25.9/14 = 1.85 mol.

The no. of oxygen moles =weight percent / molar mass = 74.1 / 16 = 4.63 mol.

Nitrogen : Oxygen

$$\frac{1.85}{1.85} : \frac{4.63}{1.85}$$

1 : 2.5

So, the ratio between Nitrogen and oxygen = 1 : 2.5 (we multiply both sides by 2 because decimals such as "2.5" cannot be used in chemical formulas) = 2 : 5

The chemical formula = N_2O_5

The no.chemical formula units =*The molar mass of compound the molar mass of chemical formula units*

Molecular formula: *The symbolic formula of the molecule of a compound which describes the kind and the actual no. of the atoms forming that molecule*

Example:-

Acetic acid of weight 60 gm contains 40% carbon, 6.67% hydrogen and oxygen 53.33%

(C=12, O=16, H=1). Calculate its molecular formula

Solution:-

Oxygen : Hydrogen : Carbon

$$\frac{53.33}{16} \quad \frac{6.67}{1} \quad \frac{40}{12}$$

6.67 3.33 3.33

1 2 1

The empirical formula: *CH_2O*

The molar mass of Acetic acid = 12 + 1+1+16 = 30 gm

The no. of units = 60/30 = 2 units

The molecular formula = *$CH_2O \times 2 = C_2H_4O_2$*

Actual and theoretical yields

When a chemical reaction occurs to get certain amount of chemical substances, the chemical equation of the reaction determines theoretically the

amount of the products. But practically, the amount of the products will be less than the theoretical amount because:-

1- The products may be volatile and parts of them spread in the air

2- Parts of the products may stick to the glass containers walls

3- The reactants may be impure

4- side reactions may occur

Practical yield: *The amount of substances we get practically from the reaction*

Theoretic yield: *The amount of substances we expect to get form the reaction*

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e percentage yield ***(the percentage of practical yield)*** *= 100 x* $\frac{\text{Practical yield}}{\text{Theoretical yield}}$

Example:

Methyl alcohol is produced under high pressure through the following reaction:

$CO_{(g)} + 2H_{2(g)} \xrightarrow{\Delta} CH_3OH_{(l)}$

If 6.1 g of methyl alcohol is produced from a reaction of 1.2 g of hydrogen with abundance of
carbon oxide, calculate the percentage of the actual yield
(C = 12 , O = 16 , H = 1).

Solution:

Molecular molar mass $CH_3OH = 1 \times 4 + 16 + 12 = 32$ *g*

2 mol of H2 Produce 1 mol of CH_3OH

4 g Produce 32 g

1.2 g Produce X g

So X (mass CH_3OH *theoritical) =* $\frac{32 \times 1.2}{4} \times 100$

$= 9.6$ *g*

Percentage of actual yield = $\frac{6.1}{9.6} x100 = 63.54\%$

Questions of lesson(2)

1- Choose

1- The empirical formula of $C_4H_8O_2$ is…….

A- C_2H_4O B- C_4H_2O C- CH_4O_2 D- $C_2H_8O_2$

2- The no. of empirical formulas in $C_2H_2O_4$ is …..

A-1 B-2 C- 3 D-4

3- If the empirical formula of a compound is CH2 and its molar mass if 56g, its molecular formula is…..

A- C_2H_4 B- C_4H_8 C- C_3H_6 D- C_5H_{10}

4- If the molecular formula of Vitamin C is C6H8O6, its empirical formula is….

A- $C_3H_4O_3$ B- $C_3H_4O_6$ C- $C_3H_8O_3$ D- C_3H_6O

5- The empirical formula CH_2O describes……

A- CH_3 COOH B- $C_6H_{12}O_6$ C- HCHO D- All the previous answers

6- The hydrocarbon compound formed from the reaction of 0.1 mol. of carbon atoms with 0.4 mol. of hydrogen atoms is……

A- CH_4 B- C_2H_4 C- C_4H_8 D- C_3H_8

2- Write the scientific term

1- A method to describe chemical formula, the quantities of reactants

and products, and the conditions for chemical reaction

2- A constant no. of the ions, molecules or atoms in one mole of matter

4- A formula describes the actual no. of atoms in molecules

5- The amount of matter we get practically from the reaction

6- The sum of the atoms masses forming the molecule

7- The volumes of the reactant and products gases have certain ratios

8- The equals volume of gases in the same conditions of temperature and pressure have the same no. of molecules

9- A formula which describe the simplest ratios between the atoms forming molecules

10- The amount of reactants we expect to get from the reaction.

3- Solve the following problems

1- Find the molecular formula of a compound containing 85.7% carbon and 14.3% hydrogen whose molar mass is 42g

2- Calculate the mass percent of iron in $FeCO_3$ (Fe=56, C=12, O=16)

3- Calculate the mass percent of the elements forming Glucose sugar $C_6H_{12}O_6$

(C=12, H=1, O=16)

4 - 130g of silver chloride (AgCl) precipitated when a mole of sodium chloride (NaCl) reacted with silver nitrates ($AgNO_3$), calculate the percentage yield (percentage of actual yield) (Ag=108, N=14, Cl= 35.5, Na= 23,O=16)